APPLICATION OF THE WHITE LIGHT SPECKLE METHOD TO FRACTURE STUDIES

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ABSTRACT

A new optical method utilizing an artificially generated random (speckle) pattern and illuminated in non-coherent (white) light is used to measure the deformation field around cracks. A brief description of the method is followed by the application of the method to determining the displacement field around a crack of a double cantilever beam specimen. Crack opening displacement and stress intensity factors obtained from these data are seen to agree well with theoretical predictions.

KEYWORDS

Speckle, White Light, Displacement, COD, SIF.

INTRODUCTION

The white light speckle method has recently been shown to be a versatile method for experimental strain analysis (Chiang and Asundi, 1979; Boone and Debacker, 1976; Forno, 1975; Asundi and Chiang, 1983). It has been applied to the determination of strain on both the surface and interior (Asundi and Chiang, 1983) on flat as well as curved objects (Chiang and Asundi, 1981). The method is very straight forward and the sensitivity can be adjusted to suit our particular needs. In this paper, the white light speckle method has been applied to problems in fracture mechanics and it is shown that this method is capable of measuring the displacement field around a crack tip and hence enabling us to deduce the various fracture mechanics parameters such as COD, stress intensity factor etc.

THE WHITE LIGHT SPECKLE METHOD

The white light speckle method consists of first creating a random pattern (called speckles) on the surface of the object. For interior deformation measurements some form of inhomogenity is created inside the 3-D object.

The simplest means of creating this speckle pattern is to paint the surface with retroreflective paint, the beads in which produce the required pattern. Other means of creating this random pattern is shown in Fig. 1. The object

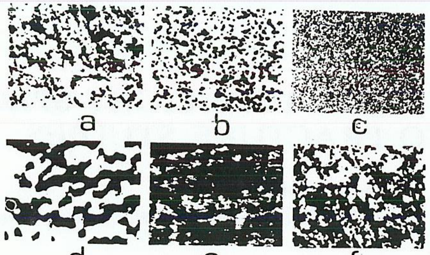


Fig. 1. Surface preparation for creation of white light speckles.
(a) Black paint sprayed on white base.
(b) Surface coated with retroreflective liquid.
(c) Laser generated speckle pattern created on stripping film stuck to surface
(d) Surface texture of concrete wall.
(e) Surface texture of machined aluminium block.
(f) Surface texture of wooden block.

is then illuminated in white light such as from an ordinary slide projector, and the speckle pattern recorded on film. If an imaging device such as a camera lens is used for this recording (Fig. 2a), the method is referred to as the subjective white light speckle method. If, however, the speckles are

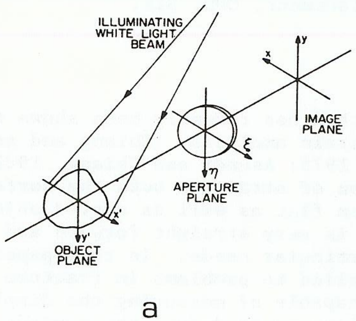


Fig. 2(a). Schematic for recording subjective white light specklegrams.

recorded directly on the film which is attached to the specimen (Fig. 2b), then we have the objective speckle method.

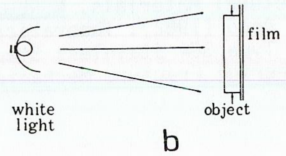


Fig. 2(b). Schematic for recording objective white light specklegrams.

For deformation analysis, two exposures of this pattern are recorded on the same film. The first exposure is before, and the second after the application of a load. The processed negative, referred to as a specklegram, has a record of the relative in-plane displacement experienced by the object in between exposures. This relative displacement can be delineated from the specklegram using either the pointwise or whole field filtering techniques. In the pointwise method (Fig. 3a), a narrow beam of laser light illuminates

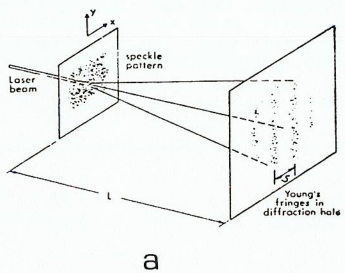


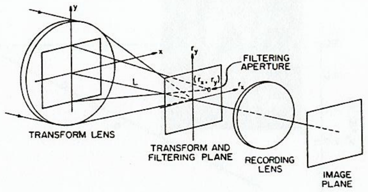
Fig. 3(a). Optical arrangement for pointwise filtering.

a point on the specklegram. The diffracted light, observed at a distance L from the film, contains parallel equi-spaced fringes bounded in a halo. The spacing between the fringes, S, is inversely proportional to the magnitude of the total displacement vector $|\vec{u}|$ at the point where the laser beam illuminates the specklegram, and the direction of displacement is normal to the fringe orientation. The governing equation for fringes is

$$|\vec{u}| = \frac{\lambda L}{S} \qquad [1]$$

where λ is the wavelength of the laser light. Thus by scanning across the specklegram one can obtain a complete map of the in-plane displacement.

In the wholefield approach (Fig. 3b), the specklegram is placed in a convergent beam of laser light. When viewed through an aperture placed at $\vec{r}(r_x , r_y)$ on the transform plane, the isothetics (i.e. fringes representing displacement component in the direction $\vec{r}$) are observed. These isothetics are governed by



b

Fig. 3(b). Optical arrangement for wholefield filtering.

$$\vec{u} \cdot \vec{r} = N \lambda L \qquad [2]$$

where N is the fringe order.

The sensitivity and orientation of the isothetics can be controlled by varying the position of the aperture on the transform plane.

APPLICATIONS TO FRACTURE STUDIES

Among the various crack configurations studied was a double cantilever beam specimen shown in Fig. 4. The model material was perspex, although this

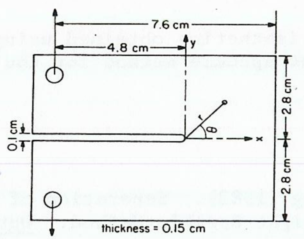


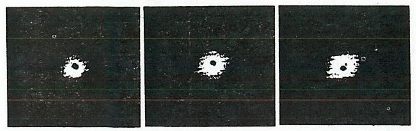
Fig. 4. Schematic of specimen geometry.

technique can just as easily adopted to any other material. Both the subjective and the objective white light speckle methods were adopted for this problem.

SUBJECTIVE WHITE LIGHT SPECKLE APPROACH

For the subjective white light speckle method, the artificial speckle pattern was created as follows. The surface was first painted white and then spray painted black, thereby generating the random black and white speckle pattern.

The specimen was then illuminated by a tungsten light source and imaged at 10 X magnification. A special loading jig was designed to apply constant displacement to the two legs of the double cantilever beam. A double exposure of the speckle pattern on the object was recorded on Kodalith Ortho film before and after the application of load. The processed negative was filtered using both the pointwise and wholefield methods. Fig. 5a shows the



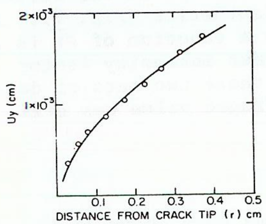
a

b

Fig. 5(a). Young's fringes along a direction perpendicular to crack tip for the double cantilever beam.

(b). u_x and u_y isothetics for same specimen.

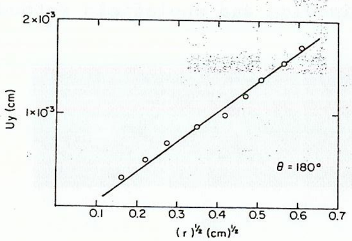
pointwise filtered (so called Young's) fringes at select points perpendicular to crack tip. Fig. 5b are the wholefield isothetics obtained by positioning the aperture along the x and y directions respectively. A plot of the displacement component in the y-direction along the crack length as obtained from Fig. 5b and equation (2) is the crack opening displacement (Fig. 6a)



a

Fig. 6(a). Displacements relative to crack tip along y direction from Fig. 5(b).

and is seen to follow the $\sqrt{r}$ distribution predicted by theory. If, however, the displacement u_y is plotted against $\sqrt{r}$ (Fig. 6b), the slope of the



b

Fig. 6(b). Vertical displacement field along the crack from Fig. 5(b).

resulting least squares fitted line is proportional to the Stress Intensity Factor which for this case is 55.4 $(\mathrm{Kg/cm^2})\sqrt{\mathrm{cm}}$. Similar estimates of the stress intensity factor can be obtained from plots of u_x v/s $\sqrt{r}$ and $|\vec{u}|$ v/s $\sqrt{r}$. These estimates of SIF are within 10% of that predicted by theory (Rooke and Cartwright, 1976), while the average value is within 5% of the theoretical result.

OBJECTIVE WHITE LIGHT SPECKLE APPROACH

A similar specimen as before was used. The random speckle pattern was generated by first polishing the surface with fine grained emery paper, followed by sanding using liquid containing 1 u sized alumina particles. The specimen was illuminated via an ordinary slide projector and the previously used loading jig modified to facilitate placing the photographic plate in close contact with the specimen. A double exposure of the speckle pattern was recorded on this photographic plate before and after the application of a load. The processed plate was filtered using the wholefield method to reveal the u_x and u_y isothetics (Fig. 7). As before the plot of either displacement component as a function of $\sqrt{r}$ is a straight line whose slope is proportional to the stress intensity factor. Once again the stress intensity factor from either of these two sets of data was within 10% of the theoretical value, while the averaged value was still a better estimate.

CONCLUSIONS

The white light speckle method has been shown to be a useful tool for displacement measurements in an effort to solve problems in fracture mechanics. The method is very simply applied and can be used on both flat and curved surfaces to measure displacements on the surface or the interior.

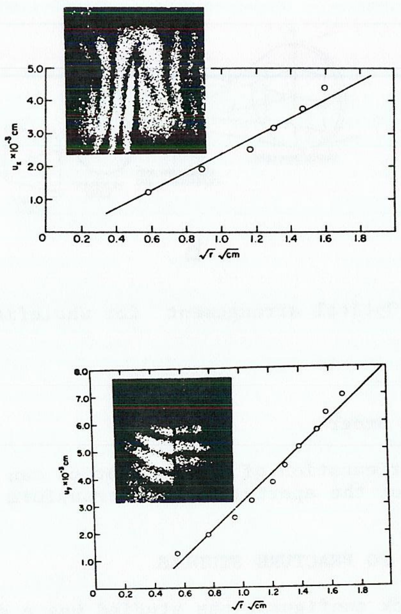


Fig. 7. u_x and u_y isothetics obtained using the objective white light speckle method for the double cantilever beam.

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